Electric Dipole Moments as Probes of CPT Invariance

Pavel A. Bolokhov

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Introduction

- Electric Dipole Moments (EDM) provide an important test of P and T symmetries

$$H = -\mu \mathbf{B} \cdot \frac{\mathbf{S}}{S} - d\mathbf{E} \cdot \frac{\mathbf{S}}{S}$$

- at very high energy scales, New Physics which creates EDM can in principle be violating CPT and Lorentz invariance
- An example of that is a CPT-nonconserving EDM

$$\mathcal{L}_{\rm EDM} = \frac{-i}{2} d_{\rm CP} \cdot \overline{\psi} \sigma^{\mu\nu} F_{\mu\nu} \gamma^5 \psi \; + \; d_{\rm CPT} \cdot \overline{\psi} \gamma^\mu \gamma^5 \psi \, F_{\mu\nu} n^\nu$$

- In general, one has both CP- and CPT-breaking contributions to EDMs

- We investigate Lorentz-violating (LV) physics at the level of dimension *five* operators
- In the Standard Model at 1 GeV there is one vector LV operator inducing EDM

$$\mathcal{L}^{\rm vector}_{\rm CPT} = \sum_{i=u,d,s} d_i^\mu \cdot \bar{q}_i \gamma^\lambda \gamma^5 F_{\lambda\mu} q_i$$

analogous operators for leptons vanish on the equations of motion.

- and a number of tensor operators with EDM-like signatures

$$\mathcal{L}^{\rm tensor}_{\rm CPT} = \sum_{i=u,d,s,e,\mu} D_q^{\mu\nu\rho} \cdot \overline{\psi}_i \gamma_\mu F_{\nu\rho} \gamma^5 \psi_i \; + \; + \sum_{i=u,d,s} \widetilde{D}^{\mu\nu\rho} \cdot \overline{\psi}_i \gamma_\mu G^a_{\nu\rho} t^a \gamma^5 \psi_i$$

- We investigate Lorentz-violating (LV) physics at the level of dimension *five* operators
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$$\mathcal{L}^{\rm vector}_{\rm CPT} = \sum_{i=u,d,s} d_i^\mu \cdot \bar{q}_i \gamma^\lambda \gamma^5 F_{\lambda\mu} q_i$$

- The important property: they *preserve chirality*. Thus, unlike ordinary EDMs, *decouple linearly* with the scale of New Physics:

$$d^\mu_{\rm CPT} \propto \Lambda^{-1}_{\rm CPT}\,, \quad \text{whereas} \quad d_{\rm CP} \propto m_q \Lambda^{-2}_{\rm CP}$$

- Vector LV operators in the quark sector induce EDM of the neutron

$$d_n = 0.8 d_d^0 - 0.4 d_u^0 - 0.1 d_s^0$$

  where the current experimental constraint $|d_n| < 6 \times 10^{-26} e\text{cm}$ can be applied.

- EDMs of diamagnetic atoms have a suppression due to preserved chirality — the Schiff moment is induced by the EDMs of nucleons and *not* by the π-exchange.

- By the same reason, EDM of a deutron is suppressed as $\alpha m_q / \Lambda_{\text{QCD}}$.

- This way, a *discretion between CPT-odd and CP-odd EDMs can be done*.

- Tensor operators at the Quantum Mechanical level are represented as

$$H = -\mu \mathbf{B} \cdot \frac{\mathbf{S}}{S} - \mathcal{D}^{ij} E_i \cdot \frac{S_j}{S}$$

  which further produces $E_i B_k \mathcal{D}^{ik}$ — an EDM-like signature. One expects a 12/24 hour modulation due to rotation of the Earth.

- In paramagnetic atoms, atomic EDM occurs due to mixing between electron levels of opposite parity. The resulting EDM is enhanced w.r.t. electron EDM: $d(\mathrm{Cs})/d(\mathrm{e}) = 7$, thus $|\mathcal{D}_{ik}| \; < \; 10^{-25} e\mathrm{cm}$.

- The most stringent constraints exist on dimension *three* LV operators, *e.g.*

$$b^\mu \cdot \overline{\psi}\gamma_\mu\gamma_5\psi$$

- Dimension five interactions are hard to propagate into dimension three ones as this involves CP-violation. Nevertheless,

$$\Lambda_{\rm CPT} \sim 10^{11-13}\,{\rm GeV}$$

Conclusions

- CPT-odd EDMs provide a way of probing New Physics governing at high energies
- Clock-comparison and EDM-searching experiments allow for putting constraints on parameters of the CPT-breaking theory
- Suppression of CPT-odd EDMs in certain cases provides a way of distinguishing CP-odd EDMs from the latter ones.